Discrete Element Study Mixing in an Industrial Sized Mixer

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Abstract
The mixing quality as function of the operating time is one major parameter to be considered for the design of industrial sized mixers. Different mixer types with different operating principles can be found for different special tasks, and the question about the proper quantity that quantifies mixing is still open.
Computer simulations based on the Discrete Element Method (DEM) provide a close, detailed look inside the mixing device and process and thus a better understanding of the particle flow in the mixer. Therefore such simulations can be used for an improvement of the mixer design or operating conditions.
DEM simulations allow the "online"- and "inline"-measurement of the mixing quality over time. But in mixers with a complex design it is not only interesting at which time a certain mixing quality is reached. It is also interesting to analyse which part of the mixing (either location in the device or process conditions) are of special importance due to a strong effect on the mixing process.
Therefore, a time- and space-dependent analysis was developed, using several approaches for mixing-quality that can be found in literature. More explicitly, the particle numbers, the number of contacts between different particle-types, and the generalized mean mixing index (GMMI) have been examined. All have their regimes of reasonable use that will be discussed - the most promising approaches will be compared.

1 Introduction

The mixing of particles is an important process in chemical, food and process engineering, needed to reach a certain product quality. A lot of mixing technologies exist for different purposes. In contrast to relatively simple mixing principles like stirring, which are widely used on a laboratory scale, industrial mixers often posses a complex shape – of the mixer itself or of its components – and a usually simple kinematics of the moving parts (e.g. rotation around one axis). For the optimisation of design and operational parameters and for the adaption of the mixer parts to different bulk solid properties, expensive experimental tests are usually necessary. Unfortunately, it is often difficult to observe what is really going on in the experiments, because a direct analysis of the particle behaviour is not possible.
Discrete element simulations offer the possibility of such a direct analysis of the particle motion and their interactions with the mixer parts. A lot of work already has been done concerning the application and verification of mixer simulations, mainly on a small

laboratory scale [1,2]. Increasing computational power and idealised simulation models allow also the simulation of large scale industrial mixers like the Lindor mixer shown in Fig. 1.

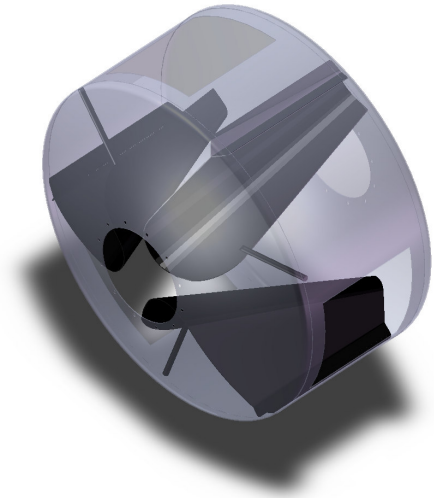

Fig. 1: 3d-CAD model of an industrial mixer from Lindor [3]

After the serial filling of the mixer (at rest) with the bulk material, using the axial inlet opening, the drum and the blades rotate with low rotation speed (typical 10-20 rpm) and mix the material. Depending on the size of the drum – mixers for 10 – 25,000 litres are available – good mixing can be achieved for small amounts of precious materials or for large, industrial scale amounts of bulk materials, in a fast and gentle mixing procedure that characterises the Lindor mixer [3].
The picture sequence from a DEM simulation, as shown in Fig. 2, gives an idea how a binary particle system with different particle sizes behaves in the Lindor mixer during start up (steady state and the discharge of the material is not shown).

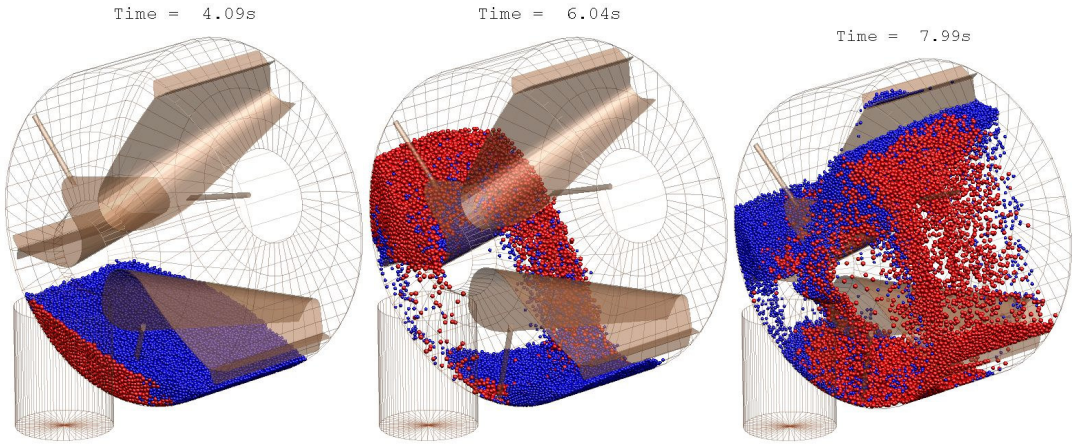

Fig. 2: Picture sequence from a DEM simulation with 10 rpm, rotation is clockwise, of a binary distributed particle system in a Lindor mixer (left) after filling, just before rotation starts, (middle) after the first blade has moved 1/3, i.e., half-way up, and (right) after the first blade has moved 2/3 around.

2 Analysing the mixing quality

For the optimisation of the design and operational parameters it is necessary to evaluate the mixing quality dependent on time and ideally also as function of space. Different approaches can be used for such an analysis.

2.1 Contact number calculation

One of the easiest ways to characterise the mixing quality (from DEM data) is to count the number of contacts between the two bulk materials, in this case between small (blue in Fig. 2) and large (red) particles. The ratio of the small-large contact number C_{sl} and the total contact number C_{total} can be used for characterising the mixing quality, called q_1:

$$q_1 = \frac{C_{sl}}{C_{total}} \tag{1}$$

Bad mixing corresponds to small values of q_1, (artificial) optimal mixing would correspond to unity and good mixing is indicated by values between 0.2 and 0.5 already. Counting the numbers of contacts is better/easier than using statistical analysis variance, standard deviation or statistical entropy [4]. While the time dependency of the mixing quality can be well observed calculating q_1 for all particles, see Fig. 3 (left), it is not possible, however, to understand the spatial dependency with a single q_1 value. For this, the whole model has to be divided in cells and the q_1 value has to be calculated in each cell. Only a picture sequence or a video can show where and when the highest mixing rates occur in the model, see Fig. 3 (right), which cannot be shown here.

The cumulative analysis of q_1, that means the calculation of the sum of the q_1 values for each cell during the simulation, allows a much easier prediction of the zones with highest mixing rates, but it can also lead to misinterpretations and should only be used together with the analysis of the general particle flow.

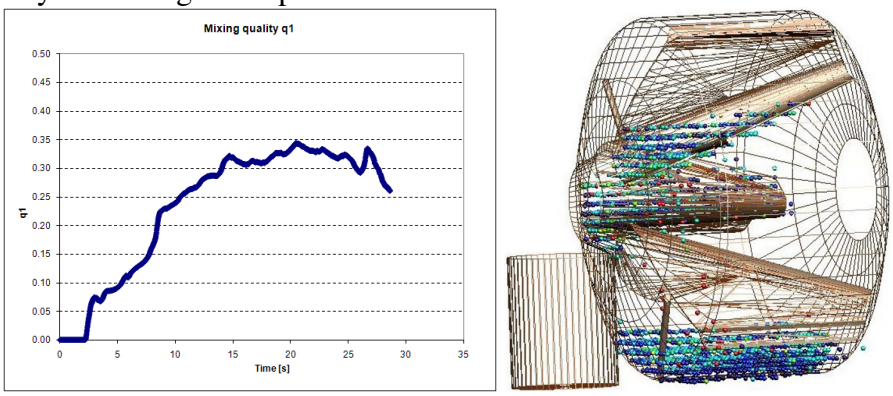

Fig. 3: (Left) Mixing quality (global) in the mixer plotted against time. (Right) Spatial dependency of the mixing quality at simulation time 10.18s. The mixing quality q_1 is calculated for each cell represented by a single particle. The colour code represents the mixing quality q_1: 0  1.

2.2 Generalized Mean Mixing Index (GMMI)

Although the local quality of mixing cannot be rigorously described by a single number, a simple number description would be very helpful for many practical reasons. For this reason, the General Mean Mixing Index GMMI introduced in [5] is applied, as an alternative, for further analysis. The GMMI has several advantages over statistical

methods like Lacey index, Anova, Manova, etc. The primary advantage is that a sampling is not required in this method.

$$GMMI_i = (GMMIx_i + GMMIy_i + GMMIz_i)/3 \tag{2}$$

Where, $GMMIx_i$, $GMMIy_i$ and $GMMIz_i$ are the Generalized Mean Mixing Indices in x, y, z coordinates, respectively. For example, $GMMIz_i$ is simply the mean of the z-coordinate of particle centre of type i divided by the mean of the z-coordinate of all particles. It is calculated as follows

$$GMMIz_i = \left[\frac{\sum_{j=1}^{n}(z_j - z_{ref})}{n}\right] \Big/ \left[\frac{\sum_{k=1}^{N}(z_k - z_{ref})}{N}\right] \tag{3}$$

Where n is the number of particles of type i, N is the total number of particles, z is the z-coordinate of the position of the particle centre and z_{ref} is the reference z-coordinate. Thus, z-mean is calculated relative to a reference z-coordinate such as the centre of the system. $GMMIx_i$ and $GMMIy_i$ are calculated similarly.

Similar to the spatial q_1 calculation, the whole model has to be divided in cells. In this case however, the mixing index is not objective, i.e., the choice of the reference point is essential for a reasonable analysis.

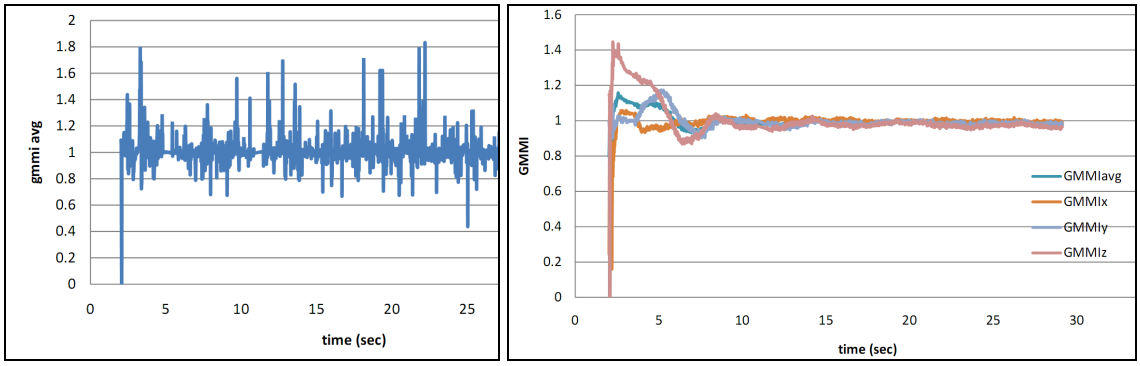

Fig. 4: (Left) Average GMMI value of all cells with the reference point at the bottom of the mixer. (Right) Average GMMI and directed GMMIs of all cells with the reference point at the centre of each cell.

Fig. 4 shows the difference between the average GMMI values of all cells, dependent on the chosen reference point. The left diagram in Fig. 4 shows large fluctuation of the GMMI value, whereas the right shows the improvement of mixing (approach to unity) basically. The continuous improvement of the mixing quality, up to 15 seconds, which is shown in Fig. 3 (left) can not be seen here in Fig. 4. In the left panel, there is no change of mixing quality visible at all, while in the right, the change vanishes around 10 seconds already.

When a single cell is considered, a certain correlation between q_1 and GMMI can be recognised, as displayed in Fig. 5.

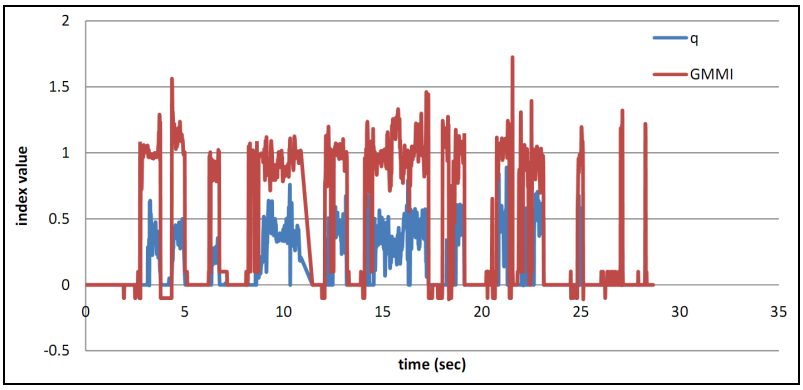

Fig. 5: Comparison between q_1 and GMMI mixing indices for a single cell at the bottom of the mixer. The zero values correspond to the times when the cell is empty.

Although the GMMI may be a good analysing method for certain mixing processes, it shows for the Lindor mixer only locally some basic correlation with the observed particle behaviour and with the calculated q_1 values. In contrast, the q_1 number already gives a global quantitative information on the mixing quality.

3 Conclusions

DEM simulations are a universal tool for the analysis of particle systems and processes. Industrial sized mixers can be simulated considering the real geometry and motion of the mixer, using idealised particle properties, if necessary. The calculation of the fraction of inter-species contact numbers, the q_1 value, is a promising method for the evaluation of the global and the local mixing quality. The calculation of the GMMI values results in no additional benefit for the examined problem.

Additional simulations (data not shown) indicate that modifications in rotation rate, mixer geometry or material parameters (like for example the friction coefficient) affect the mixing behaviour. A more detailed analysis of these dependencies, in the future, will allow to identify the most important system parameters and, eventually, to propose an improved design for the mixing device.

References

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